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Ecofriendly Approach for the Biosynthesis of Zinc Oxide Nanoparticles and their Applications in Agriculture: A Review

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***Abstract*: Zinc oxide nanoparticles gained the attention of researchers due to their physical and chemical properties. Antimicrobial activity is an important factor to focus on these metal oxide nanoparticles. Zinc is an important micronutrient for plants and humans. The deficiency of Zinc in crops is a big problem worldwide, which indirectly affects humans. Large amounts of inorganic fertilizers creating environmental problems along with health issues. To overcome these problems researchers are focusing on the development of nano fertilizers with additional benefits. Green method based synthesis of metal oxides is an eco-friendly and cost-effective method. In this review article, we discussed the current status of zinc oxide nanoparticles and their applications, especially in the agriculture sector.**

***Index Terms*: Zinc oxide, Nanoparticles, Nano fertilizer, Conventional fertilizer, Antimicrobial.**

I. INTRODUCTION

Nanotechnology is a modern material science which is rapidly developing in the last few years. Nanotechnology is the engineering at the scale of atoms and molecules and their manipulation to develop new tools. Nanomaterial has special properties over the bulk. Nanoparticles are very small structures, which have dimensions less than 100 nm (Li *et al*., 2011). Various properties like surface area, size, thermal conductivity, catalytic reactivity, optical properties (Agarwal *et al.,* 2017) of metal oxide nanoparticles attracting researchers to develop new tools and techniques in different scientific fields.

To fulfil the need of a large population of the world forced the agricultural sector to increase productivity. Nutrient deficiency in soil affects farmers economically and decreases the quality and quantity of crops for human beings and pet animals (Solanki *et al*., 2015). Chemical fertilizers work as double edge swords because it increases the production of crops while on the other side it disturbs the chemical contents of the soil and decreases soil fertility along with polluting groundwater. That is why chemical fertilizer is not a good option for long term practices of agriculture (Solanki *et al.,* 2015).

Nanotechnology provides many ways for the cost-effective production of physiologically important metal nanoparticles like Zinc oxide. These nanoparticles were utilized for the formulation of fertilizer called nano-fertilizer. Plants can uptake nanoparticles more efficiently with minimum loss. Nanoparticles have a small size, large surface area, targeted delivery and controlled release kinetics makes them a perfect delivery system. It has been reported that nano-fertilizers play an important role in the rate of seed germination, seedling growth, photosynthesis, nitrogen metabolism, and biomolecule synthesis (Solanki *et al.,* 2015).

Zinc is an essential micronutrient for the human, it participates in the activities of enzymes like carbonic anhydrase, alcohol dehydrogenase and carboxypeptidase, it also involves in other physiological functions of eukaryotes (Jansen *et al.,* 2009; Maremanda *et al.,* 2014). Zinc is an important micronutrient that participates in plant growth, it is an essential component involved in metabolic reactions. Symptoms of Zinc deficiency vary according to plant species but band striped and yellow leaves are the common symptoms. The deficiency of Zinc can lead to significant decreases in crop productivity and nutritional quality. Zinc deficiencies may be present in up to 50% of the world's crop soils (University of Minnesota: Zinc for crop production). When nanoparticles are used as nano fertilizers, they can be easily absorbed and translocate in plant cells, which increased the effectiveness of fertilizers (Carpita *et al*., 1979; Remya *et al*., 2010). Lin and Xing (2008) reported the translocation of zinc oxide nanoparticles up to the shoots from the roots in ryegrass. Along with it, ZnO nanoparticles show greater potentials against different plant pathogens. It is proved that ZnO nanoparticles can work as anti-bacterial agents, as fungicides and as an insecticide (Al-Dhabi *et al.,* 2018; Sirelkhatim *et al*., 2015). This review article will provide information regarding the fundamental concepts of nanotechnology, nanoparticles, ZnO nanoparticles and their applications, specific in agriculture.

II. NANOTECHNOLOGY AND NANOPARTICLES

The concepts of Nanotechnology were first given by physicist Richard Feynman in his talk *There's Plenty of Room at the Bottom* in 1959. He described that the synthesis of nanoparticles is possible through the manipulation of atoms. He said that "Nanotechnology mainly consists of the processing of separation, deformation and consolidation of material by one atom or by one molecule". With the concept of Feynman, in 1986, K. Eric Drexler used the term "nanotechnology" in his book *Engines of Creation: The Coming Era of Nanotechnology*. The term "Nanotechnology" was first given by Norio Taniguchi in 1974 (Goswami *et al.,* 2017). The word 'nanotechnology' was popularized by scientist "K. Eric Drexler" in 1980. He has discussed the concept of development machines on the molecular scale-like development of motors, robots in the nanometer range.

A particle under the 1 to 100 nanometer in diameter is called a nanoparticle. The term is also used for bigger particles or fibres and tubes which are less than 100 nm with 2D. Particles less than 1 nm are referred to as atom clusters. Nanoparticles have differed from microparticles, fine particles and coarse particles because their smaller size nanoparticles exhibit different physicochemical properties (Vert *et al.,* 2012; U.S. Environmental Protection Agency). 1 to 1000 nm nanoparticles are very small which are not visible under the light microscope, so we required the electron microscope to see these particles. Due to this reason, the suspension of nanoparticles can be transparent, besides it, the solution of larger particles can be able to scatter some visible light. Nanoparticles cannot be easily separated from the solution through common filters; it requires a unique nanofiltration technique (Chae *et al*., 2003; Jean *et al*., 2011).

Nanoparticles possess shape and size associated properties. These properties were provided with a wide range of applications as catalysts, antimicrobial agents, chemical sensors, electronics and many more (Tan *et al*., 2006; Lee *et al*., 2008; Pissuwan *et al*., 2006).

III. TYPES OF NANOPARTICLES

Nanoparticles are different types depending upon size, morphology, chemical and physical properties. The major are- Carbon-based nanoparticles, Metal nanoparticles, Semiconductor nanoparticles, Polymeric nanoparticles, lipid-based nanoparticles.

A. Carbon-Based Nanoparticles

Carbon-based nanoparticles consist of the strong bonding of carbon to carbon atoms like Carbon Nanotubes and Fullerenes. Rolled graphene sheet used to make Carbon NanoTube. This material was used to build the strongest structure constructions. As compare to steel, CNT based structures are stronger. CNTs generally are two types, single and multi-walled. CNTs have special thermal properties is thermally conductive along the length. Fullerenes are the allotropes of carbon that form hollow cages of 16 or more carbons. For example, football-shaped structure C-16 is called Buckminster-fullerene. The arrangement of carbon in this structure is pentagonal and hexagonal. Fullerenes have special properties like electrical conductivity, electron affinity and high strength makes them commercially applicable (Saeed and Khan, 2016, 2014).

B. Metal Nanoparticles

Metal precursors are used for the production or synthesis of metal nanoparticles. Metal nanoparticles can be synthesized through chemical, physical and biological or green methods. These particles have a small size and large surface area, so they can be easily able to adsorb small molecules on their surface. These nanoparticles have a vast range of applications in different areas of research like medical, biotechnology, electronics etc. Gold nanoparticles are used for the coating of samples before analysis under an electron microscope to get high-quality images (Dreaden *et al.,* 2012; Khan *et al.,* 2019).

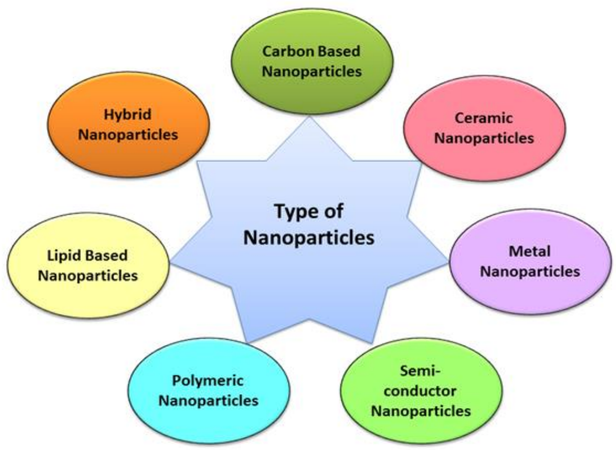

Figure 1. Types of Nanoparticles.

C. Semiconductor Nanoparticles

Semiconductor nanoparticles have properties of both metallic and nonmetallic. These particles have a special property that is a wide bandgap. They have chemical and physical properties different for their bulk or atomic structure. Semiconductor nanoparticles have wide applications in research, agriculture and in electronics. ZnO, ZnS, CdS, CdSe, GaN, Silicon, Germanium are the few examples of semiconductor nanoparticles (Ali *et al.,* 2017; Khan *et al.,* 2017a; Sun, 2000).

D. Polymeric Nanoparticles

Organic Polymer-based nanoparticles, which have different structures based on their preparation methods. The most usable structural form of these nanoparticles is nanocapsule and nanosphere. These structures are used in the protection of drug molecules, in imaging, targeting, and controlled release mechanisms. Polymeric nanoparticles are highly biodegradable and biocompatible (Mansha *et al.,* 2017).

E. Lipid-Based Nanoparticles

Lipid nanoparticles are two-layered; one is core and another matrix. The core is made up of Lipids and matrices made by lipophilic molecules. Structurally these particles are spherical with a diameter of 10 to 100 nm. These particles have a vast range of applications in biomedical fields like drug delivery agents, cancer therapy and many more (Rawat *et al.,* 2011; Puri *et al.,* 2009).

IV. PROPERTIES OF NANOPARTICLES

A. Large surface area and small size

It is the most important property of nanoparticles. The large surface area provides a platform for the attachment of molecules of interest and small size makes nanoparticles movable across or through the narrowest space. Due to these properties nanoparticles are applicable in medical sciences and research.

B. Optical properties

Nanoparticles often produce quantum effects which is the unexpected optical property. As an example, gold nanoparticles in colloidal solution appear deep red to black. Gold nanoparticles have a lower melting point as compare to gold slabs. Material with nanoparticles used for solar plate production provides better absorption of solar radiation. (Mufune *et al*., 1917; Kelly *et al*., 2005; Lu *et al*., 2007). Nanoparticles produce an extinction band in UV -visible spectroscopic analysis, which is not produced by a bulk. This situation is appearing when constant incident photon frequency excites conduction electrons collectively, known as localized surface plasmon resonance (LSPR). The wavelength of the peak of LSPR depends upon the size, shape, particles distance along with its local environment like the nature of solvent, substrate and adsorbents (Eustis and El-Sayed, 2006).

C. Thermal properties

The thermal conductivity of nanoparticles is higher than fluid having solids. The large increase in surface energy and the changes in intra-atomic spacing as a function of nanoparticle size have a marked effect on material properties. For instance, the melting point of gold/silver particles, which is a bulk thermodynamically characteristic, has been observed to decrease rapidly for particle size less than 10 nm (Kelsall *et al,* 2005).

D. Magnetic properties

A previous study showed that nanoparticles under the size of 10 – 20 nm possess maximum properties and perform well. In this size range the manganic properties of nanoparticles appear perfectly and make it more applicable (Faivre and Bennet, 2016; Priyadarshana *et al.,* 2015; Reiss and Hutten, 2005; Zhu *et al.,* 1994). The distribution of nanoparticles unevenly leads to this property; the magnetic property of nanoparticles depends on the type of synthesis. Methods like co-precipitation, microemulsion, thermal decomposition, solvothermal can be used for their preparation (Qi *et al.,* 2016; Wu *et al.,* 2008).

E. Mechanical properties

Hardness, strain, adhesion and friction are the parameters to know about the mechanical properties but in the case of nanoparticles coagulation, coating and lubrication are also counted in mechanical properties and these are the size-dependent properties of nanoparticles (Guo *et al*., 2014).

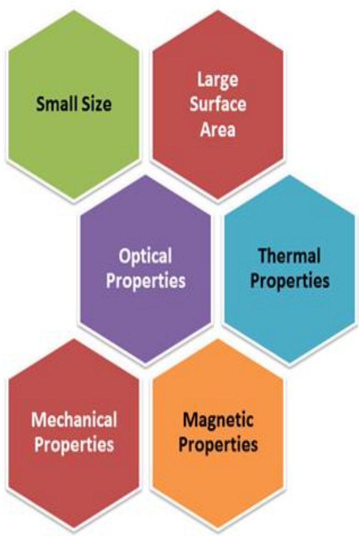

Figure 2. Properties of Nanoparticles.

V. ZINC OXIDE NANOPARTICLES

Zinc oxide is a non-hygroscopic, nontoxic, crystalline, semiconductor metal oxide and a versatile inorganic material with broad applications. ZnO has unique chemical, optical and electromagnetic properties. It can be characterized by a UV-visible spectrophotometer which shows a large energy band gap that is 3.37 eV and binding energy (60 MeV) at room temperature (Wang *et al*., 2004; Wang *et al*., 2006; Janotti *et al*., 2009; Zhang *et al*., 2012).

Zinc oxide nanoparticles have various applications in agriculture, material science, medical, food industry and others (Siddiqi *et al*., 2018). ZnO nanoparticles have very good antimicrobial activity, due to this reason it has become an interesting topic in agriculture nano-biotechnology to develop nanoparticles based nano fertilizer, fungicides and bactericides. Zinc is also an important micronutrient in plants. The deficiency of zinc in plants restricts the proper growth of plants. Semiconducting, piezoelectric and piezoelectric properties of the zinc oxide nanoparticles make it versatile in applications (Akhter *et al.,* 2011; Sasidharan *et al.,* 2013).

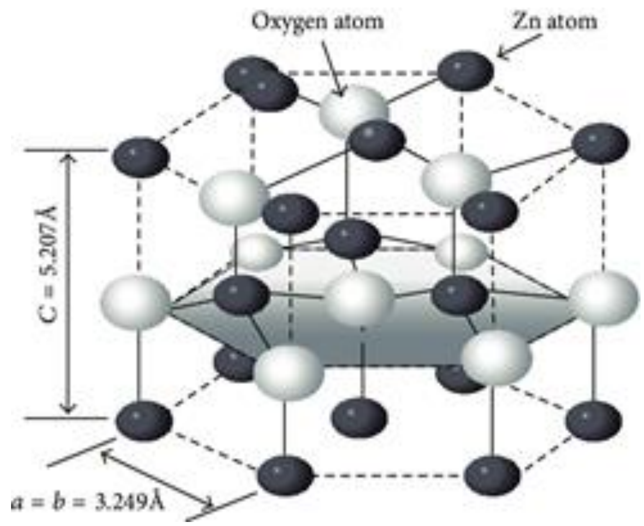

Figure 3. Tetrahedral structure of ZnO (Agarwal *et al.,* 2017).

VI. BIOSYNTHESIS OF NANOPARTICLES

Two major approaches employed for the synthesis of nanoparticles are the "*Top-down*" and *"Bottom-up"* approaches (Wang and Xia, 2004). These approaches have different protocols depending upon types of material, operation and reactions. In the *"Top-down"* approach large molecules decompose into small molecules or units. These units' converts into Nano-sized particles. This approach includes grinding, milling, chemical vapour deposition, physical vapour deposition method etc. In the *"Bottom-up"* approach nanoparticles formed from the simplest unit of the material, that is why this technique is called a building up approach. Sedimentation and reduction techniques are examples of this approach including chemical and biological synthesis, sol-gel synthesis etc. The properties of nanoparticles can be varying according to their morphology. Different methods are used to synthesize morphologically different nanoparticles or structures, which are divided into three categories are Physical, chemical and biological methods.

In the ***Physical method***, application of physical forces to reduce large particles into small particles, these structures are stable and well defined. In ***chemical approaches***, different chemicals are used to synthesize nanoparticles. These methods are fast and controllable, but chemicals create environmental pollution when they are discarded. A variety of different physical and chemical methods have been used to synthesize nanoparticles such as sol-gel, co-precipitation, hydrothermal, electrospray, ultrasonic radiation, laser chemical method, sonic state method, ultraviolet irradiation, lithography, laser ablation etc. (Din and Rani, 2016; Khandagale and Shinde, 2017; Krol *et al.,* 2017; Thakkar *et al.,* 2010).

A. Green method

Biological or Green methods involve the use of plants, bacteria, fungi, algae to synthesize nanoparticles. This approach is eco-friendly and cost-effective requires very a lower amount of energy to initiate the process (Dahoumane *et al*., 2016; El-rafie *et al*., 2013; Husen *et al*., 2014; Khan *et al.,* 2015; Patel *et al.,* 2015; Siddiqi *et al.,* 2016; Wadhwani *et al.,* 2016).

Various bacterial strains can reduce metals that were utilized to synthesize metal oxide nanoparticles (Iravani *et al.,* 2014). *Bacillus, Escherichia* is the most utilized species to synthesized Gold, Silver and Iron metal nanoparticles (Sukar *et al.,* 2012; Shivaji *et al.,* 2011; Korbekandi *et al*., 2012; Southam *et al.,* 1994; Wen *et al*., 2009; Konishi *et al*., 2007; Philips *et al*., 2002; Mann *et al.,* 1984). Shamsuzzaman *et al.,* 2014 synthesized ZnO nanoparticles of 20-30nm using live culture of *Bacillus subtilis* (Table 1).

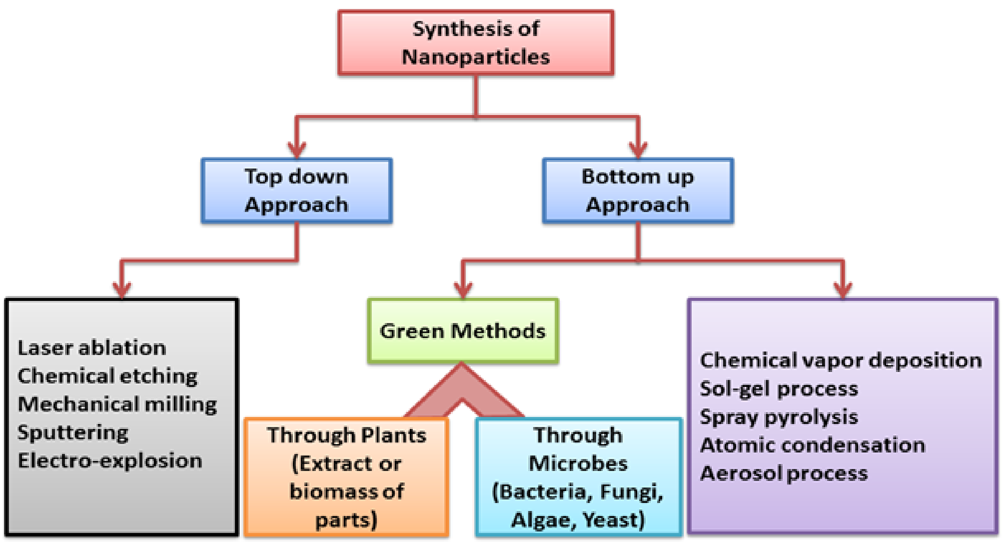

Figure 4. Different approaches for the synthesis of nanoparticles.

Fungi mediated biosynthesis of metal nanoparticles were reported. Intracellular enzymes of fungi can reduce bulk material. Fungi can synthesize large amounts of nanoparticles compared to bacterial mediated synthesis. Fungi can synthesize nanoparticles intracellularly and extracellularly. Silver, Gold and Zinc nanoparticles were synthesized successfully through *Aspergillus, Fusarium, Penicillium* and many other genera, Table. 2 (Mittal *et al*., 2013; Dwivedi *et al*., 2010; Jha *et al*., 2009; Binupriya *et al*., 2010; Ahmad *et al*., 2005; Raliya *et al*., 2014).

Plants have a variety of phytochemicals that can reduce and stabilize metal nanoparticles. The utilization of plant extracts to synthesize nanoparticles is the simplest, effective and eco-friendly approach. Initially, silver and gold nanoparticles were synthesized through different plant extracts for example Neem, Lemon, Mustard, Coriander, Tulsi, Lemongrass, Garlic and many more. According to the literature, spherical and crystalline morphologies containing metal nanoparticles were formed with different plant extracts. Nanoparticles of different shape sizes were formed through different plant extracts. The optimization of nanoparticles production is possible through the manipulation of pH, temperature, substrate concentration and other parameters.

Synthesis of ZnO nanoparticles through different plant extracts was done by many researchers. Most of the work on ZnO nanoparticles was carried out in recent years. For example, Green tea, lemongrass, Olive, rose etc. plants were used for the synthesis of ZnO nanoparticles (Table 3). Both Zinc acetate and Zinc nitrate were used as substrates. The average size of nanoparticles lies between 30 to 50 nm and most ZnO nanoparticles are spherical.

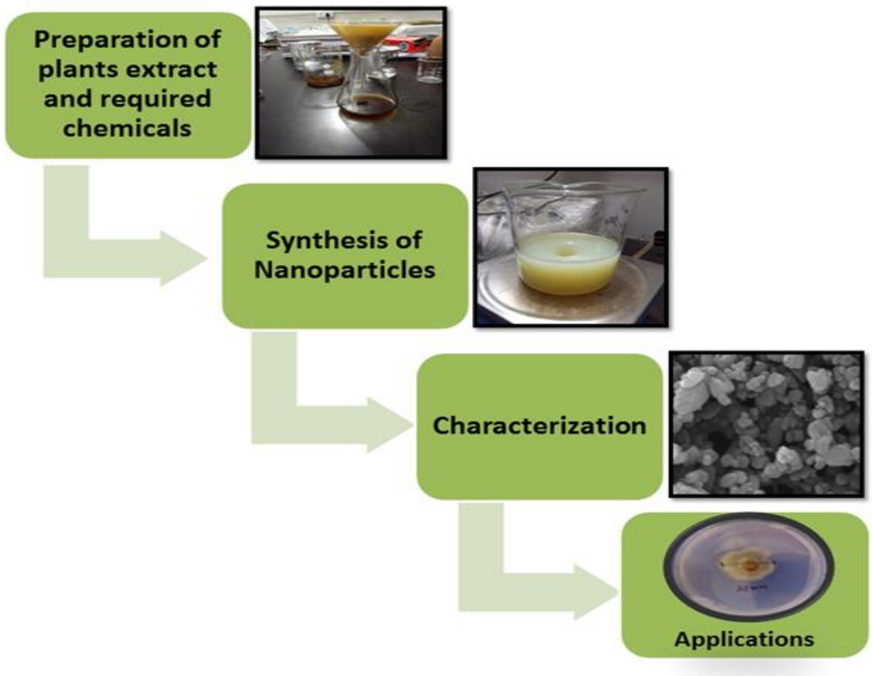

Figure 5. Easy four steps process of plants mediated green synthesis of Zinc oxide nanoparticles.

Table 1. List of bacterial strains used for the synthesis of ZnO nanoparticles.

S.No.	Name of bacterial strain	Size (nm)	Morphology	Reference
1	*Lactobacillus sporogenes*	15-May	Hexagonal	Prasad *et al*., 2017
2	*Rhodococcus pyridinivorans*	100-120	Hexagonal	Kundu *et al*., 2017
3	*Aeromonas hydrophila*	42-64	Spherical, oval	Jayaseelan *et al*., 2012
4	*Pseudomonas aeruginosa*	35-80	Spherical	Singh *et al*., 2014
5	*B. licheniformis*	40-400	Nanoflower	Tripathi *et al*., 2014

6	*Serratia ureilytica*	170-250	Spherical	Vitor *et al*., 2015
7	*Bacillus subtilis*	25	Quasi spherical	Shamsuzzaman *et al*., 2014

Table 2. List of fungus and algal strains used for the synthesis of ZnO nanoparticles.

S. No.	Name of Fungi and Algae	Size (nm)	Morphology	Reference
1	*Aspergillus fumigatus*	60-80	Spherical	Rajan *et al*., 2016
2	*Aspergillus terreus*	54-83	Spherical	Chandrasekaran *et al*., 2016
3	*Candida albicans*	15-25	Hexagonal	Shamuzzaman *et al*., 2013
4	*Aspergillus strain*	50-120	Spherical	Pavani *et al*., 2012
5	*Aspergillus fumigatus TFR-8*	7-Jan	Spherical and hexagonal	Raliya *et al*., 2013
6	*Chlamydomonas reinhardtii*	55-80	Nanorod, Nanoflower	Rao *et al*., 2016
7	*S. myriocystum*	20-36	Spherical, radial	Nagarajan *et al*., 2013
8	*Sargassum muticum*	30-57	Hexagonal	Azizi *et al*., 2013

Table 3. List of plants used for the synthesis of ZnO nanoparticles.

S.No.	Plant name	Size (nm)	Morphology	References
1	*Aegle marmelos (Indian bael)*	18 to 20	Spherical	*Fowsiya et al., 2019*
2	*Albizia lebbeck (Stem bark)*	66.25 to 112	Irregular, Spherical	*Huzaifa et al., 2020*
3	*Artocarpus gomezianus (Jackfruit leaf)*	11.53	-	*Suresh et al., 2015*
4	*Camellia sinensis (Green Tea)*	853	Irregular	*Rajesh et al., 2015*
5	*Camellia sinensis (Green Tea)*	16	Spherical	*Senthil kumar et al., 2014*
6	*Carica papaya*	114 to 168	Irregular	*Droepenu et al., 2019*
7	*Cathar anthusroseus (Pink periwinkle)*	50.73	Spherical	*Monika et al., 2018*
8	*Costus pictus (Insulin plant)*	20 to 80	Spherical, Hexagonal	*Joghee et al., 2018*
9	*Garcinia mangostana (Mangosteen)*	5 to 45	Spherical	*Mod. Aminuzzaman et al., 2018*

10	*Gigantic swallow-wort plant*	28.38	-	*Pankaj et al., 2015*
11	*Hibiscus sabdariffa (Roselle leaf)*	12-46	Spherical	*Niranjan et al., 2015*
12	*Laurus nobilis (Bay)*	21.49 to 25.25	Spherical	*Shabnam et al., 2019*
13	*Lawsonia inermis (Mehndi)*	1 to 75	Hexagonal	*Hrishikesh et al., 2018*
14	*Lemongrass*	85-95	Irregular, Spherical	*Tushar et al., 2017*
15	*Maple leaf (Acer species)*	5 to 20	Irregular	*Singaravelu et al., 2014*
16	*Mentha piperita*	20 to 40	Quasi-spherical	*Anbuvannan, 2017*
17	*Moringa oleifera (Drumstick)*	24, 52	Spherical	*Elumalai et al., 2015; Pal et al., 2017*
18	*Musa acuminata (Banana leaf)*	40	Irregular	*Ashwath et al., 2019*
19	*Olea europaea (Olive)*	20-50	Spherical	*Elaf et al., 2019*
20	*Petroselinum crispum (Parsley)*	50, 40	Spherical	*Shirin et al., 2018*
21	*Rosa indica (Rose)*	10	Spherical	*Amrita et al., 2018*
22	*Sageretia thea*	28.09	Spherical	*Noluthando et al., 2017*
23	*Scadoxus multiflorus (Blood lily)*	100	Spherical, Irregular	*Naif et al., 2018*
24	*Solanum torvum (Turkey berry Leaf)*	34 to 40	Spherical	*Kenneth et al., 2019*
25	*Spathodea campanulata (Tulip tree)*	20 to 25	Spherical	*Ochieng et al., 2015*
26	*Trachyspermum ammi (seed)*	41	Hexagonal, Irregular	*Saravanak kumar et al., 2016*

B. Characterization of nanoparticles

Characterization of synthesized nanoparticles involves the analysis of their size, shape, surface area, chemical compositions, purity, solubility etc. Initially, to get confirmation about the synthesis of nanoparticles, usually, UV-*Vis* Spectroscopy and X-ray Diffraction are considered, by which researchers can easily get the idea about the particles concentration and their size. But to confirm the exact size and the shape of particles, electron microscopy (Scanning Electron Microscopy, Transmission Electron Microscopy) is a must; it provides the image of particles. Atomic Force Microscopy is another option to get the data about particle size and density; it provides a better resolution picture by the scanning of samples using a probe. Zeta Potential Analyzer is used to detect the charges present on the particle's surface, which provides better dispersion to particles in liquid solution. Fourier Transform Infra-Red microscopy gives the knowledge about functional groups present along with the particles, which were participated in the synthesis of nanoparticles. Energy Dispersive X-ray analysis is used to know about the molecular content of the samples. These are the major techniques that are generally used to characterize metal and semiconductor nanoparticles.

VII. APPLICATIONS OF ZnO NANOPARTICLES

Zinc oxide nanoparticles have a vast range of applications in different areas. The UV filtration property of ZnO nanoparticles makes it useful for the cosmetic industry in the manufacturing of sunscreen lotion and similar products (Wodka *et al*., 2010). ZnO nanoparticles are widely applicable in the biomedical area like in drug delivery, in anti-cancer treatments, anti-diabetic, used as an antifungal and antibacterial agent (Jiang *et al*., 2018; Carmona *et al.,* 2018). Zinc oxide nanoparticles are also applicable in Agriculture as nano-fertilizer and as anti-plant pathogenic agents (Sangani *et al*., 2015; Hameed *et al.,* 2016; Movahedi *et al.,* 2014; Martínkova *et al.,* 2009; Jain *et al.,* 2013). Studies have very clearly explained the antibacterial, antifungal and insecticidal properties of zinc oxide nanoparticles (Shah and Towkeer, 2010). (Aruoja *et al*., 2009; Huang *et al*., 2006; Sharma *et al*., 2009).

In Agriculture

Micronutrients and micronutrients are required for the growth of plants. After absorption of particles in the plant cell, nutrients are translocated to the different sites. Zinc is a major macronutrient in plants and is also an important element in human food. Various recent studies showing the utilization of Zinc oxide nanoparticles as Nano fertilizers on various crops (Sabir *et al.,* 2014). The colloidal solution of ZnO nanoparticles was applied which promotes seed germination and plant growth along with improvement in nutrition qualities (Prasad *et al*., 2012). Zinc oxide nanoparticles also show anti-microbial properties, when applying the Zinc oxide nanoparticles as nano fertilizer they can also work as an anti-plant pathogenic agent, providing dual benefits to the plants or crops.

The suitable mode of application of fertilizers depends upon the amount of fertilizer reaching the plants. Truly, very less amount of fertilizers reached the plant as their need due to evaporation, runoff, hydrolysis and many other factors are responsible for this situation. Approximately on average around 70% of NPK of conventional fertilizer could not reach the plants (Alfaro *et al.,* 2008). Due to this reason, farmers cannot get the full benefits of the money which they spend on fertilizer, which is a big economic loss for the farmers as well as for the country (Trenkel 1997; Ombodi and Saigusa 2000). The overuse of fertilizers and pesticides affects the soil nutritional balance along with environmental pollution. The excess use of fertilizer and pesticides reduces plants' ability against pathogens and pests (Tilman *et al.,* 2002). To overcome all these problems, it is necessary to optimize the use of chemical-based fertilizers and pesticides (Miransari 2011; Solanki *et al*., 2015).

The utilization of nanotechnology to modify agriculture practices. The fertilizer and anti-plant pathogenic agents in nanosize provide controlled and site-specific delivery. A controlled way of delivery of fertilizer and pesticides gives the fastest results; Nanoencapsulation provides controlled and slow delivery of nano fertilizer which is more effective, cheaper and ecofriendly (Shang *et al.,* 2019). Table 4, differentiated the nano-fertilizer and conventional fertilizer.

Table 4. Conventional fertilizers vs. nano-fertilizer (Cui *et al*. 2010; Priyanka *et al*., 2015).

Parameters	**Nano-fertilizer**	**Conventional fertilizer**
Solubility	Higher	Lower
Dispersion of micronutrients	Improved	Lower
Stability in Soil	Low	Higher
Bioavailability	Higher	Lower
Nutrient's uptake	Increased ratio	Lower uptake
Controlled release	Controlled release rate	Excess release rate
Duration of release	Extended	Used by the plant and rest is converted into an insoluble form

Loss rate	Reduced	Higher

Nanotechnology is used to modify agriculture practices. The fertilizer and anti-plant pathogenic agents in nanosize provide controlled and site-specific delivery. A controlled way of delivery of fertilizer and pesticides gives the fastest results; Nanoencapsulation provides controlled and slow delivery of Nano fertilizer which is more effective, cheaper and eco-friendly. ZnO nanoparticles affect the growth of *Cicer arietinum* and *Vignaradiata* (Mahajan *et al*., 2011). When the colloidal solution of 1.5 ppm of zinc oxide is applied through foliar spray on chickpea seedling, gives a positive effect on seedling growth (Burman *et al*., 2011). In a recent study, which was conducted by the Polytechnic University of Madrid and the National Institute for Agriculture Research and Experimentation (INIA) on the effect of ZnO nanoparticles on agriculture. They studied the effects of zinc oxide nanoparticles on Tomato and Bean plants. These effects depend on the type of crop, exposure time and pH of soil. The results seem good; ZnO nanoparticles do not pose toxicity risks and have good fertilizing properties (García-Gómez *et al.,* 2018).

There are different methods to deliver nano-formulations in the form of fertilizer or anti plant pathogenic agents. Methods depend on the culture or medium conditions of the plants. There are in-vitro and in vivo methods to deliver nano-formulations are –

In vitro methods

Aeroponics - In this technique (as their name Aero means in Air), plant roots are open in a controlled gaseous environment, the nutritional solution of media is applied through spraying. This technique is not easy to set up because it requires a high quality of nutrition and a controlled environment.

Hydroponics -In this technique, plants are grown in liquid culture, the roots of plants immersed in it. This liquid culture provides all the required nutrition required by the plants. Pathogens and high moisture conditions are the major drawbacks of this technique.

In vivo Methods

Soil Application-This is the most common technique. In this technique simply soil is used to cultivate plants. All required nutrition is provided through the soil to plants. The quality of soil also affects the growth of plants there also requires all essential elements like N, P, K. This technique is widely accepted because it provides a long run for the application of organic or inorganic fertilizers (Taiz and Zeiger 2010; Solanki *et al.,* 2015).

Foliar Application - In this technique, required nutrition is provided to the plants through spraying on plants leaves. This technique is generally used to deliver trace elements like Zinc and Iron. If we provide these kinds of trace elements through soil then there are higher chances of disturbance, because these nutrients can be absorbed by the soil and they will unable to reach the root system (Solanki *et al.,* 2015; Banotra *et al.,* 2017).

CONCLUSION

It is expected that the study on Zinc oxide nanoparticles in agriculture will provide a good nano-fertilizer and anti-phytopathogenic agent which will be suitable for all crops from each aspect like reducing the utilization of chemical-based fertilizer, provide better productivity by improving the rate of germination, seedling growth and nutritional values along with the protection from pathogens. The green method is a cost-effective and easily available source-based method for the synthesis of ZnO nanoparticles; it also reduces the cost of commercial production of ZnO nanoparticles. It is expected that future studies will also be clear about any nano-toxicity and any genetic changes in crops or plants due to the sequestration of ZnO nanoparticles and their effect on human health.

REFERENCES

Agarwal, H., Kumar, S.V. & Rajeshkumar, S. (2017). A review on green synthesis of zinc oxide nanoparticles – An eco-friendly approach. *Res-Effi Technol.* 3(4), 406-413. doi.org/10.1016/j.reffit.2017.03.002.

Ahmad, A., Senapati, S., Khan, M.I. & Sastry, M. (2005). Extra-/Intracellular biosynthesis of Gold nanoparticles by an *Alkalotolerant* fungus, *Trichothecium* species. *J of Biomed Nanotechnol.* 1(1), 47-53. doi:10.1166/jbn.2005.012.

Akhter, S., Ahmad, Z., Singh, A., Ahmad, I., Rahman, M., Anwar, M., Jain, G.K., Ahmad, F.J. & Khar, R.K. (2011). Cancer targeted metallic nanoparticle: targeting overview, recent advancement and toxicity concern. *Curr Pharm Des*. 17(18), 1834-50. doi:10.2174/138161211796391001.

Al-Dhabi, N.A. & Arasu, M.V. (2018). Environmentally-friendly green approach for the production of zinc oxide nanoparticles and their anti-fungal, ovicidal, and larvicidal properties. *Nanomat (Basel).* 8(7), 500. doi: 10.3390/nano8070500.

Ali, S., Khan, I., Khan, S.A., Sohail, M., Ahmed, R., Rehman, A., UrAnsari, M.S. and Mors, M.A. (2017). Electrocatalytic performance of Ni@Pt core-shell nanoparticles supported on carbon nanotubes for methanol oxidation reaction. *J Electro Chem*. 795, 17-25. doi.org/10.1016/j.jelechem.2017.04.040.

Alrubaie, E.A.A., & Kadhim, R.E. (2019). Synthesis of ZnO nanoparticles from olive plant extract. *Plant Arch.* (19), 339-344.

Alfaro, M., Salazar, F., Iraira, S., Teuber, N., Villarroel, D. and Ramírez, L. (2008). Nitrogen, Phosphorus and Potassium losses in a grazing system with different stocking rates in volcanic soil. *Chilean J of Agri Res*. (68), 146-155.

Aminuzzaman, M., Ying, L.P., Goh, W.S. & Watanabe, A. (2018). Green synthesis of zinc oxide nanoparticles using aqueous extract of *Garcinia mangostana* fruit pericarp and their photocatalytic activity. *Bul of Mat Sci*. 41(2), 50. doi:10.1007/s12034-018-1568-4.

Anbuvannan, M., Ramesh, M., Viruthagiri, G., Shanmugam, N. & Kannadasan, N. (2015). Synthesis, characterization and photocatalytic activity of ZnO nanoparticles prepared by biological method. *Spectrochim Acta A Mol Biomol Spectrosc,* 15(143), 304-308. doi:10.1016/j.saa.2015.01.124.

Anveka, T.S., Chari, V.R. & Kadam, H. (2017). Green synthesis of ZnO nanoparticles, its characterization and application. *Mat Sci Res,* 14(2), 153-157.

Aruoja, V., Dubourguier, H.C., Kasemets, K. and Kahru, A. (2008). Toxicity of nanoparticles of CuO, ZnO and TiO2 to microalgae *Pseudo Kirchneriella subcapitata*. *Sci of the Tot Env*. 407(4), 1461-8. doi:10.1016/j.scitotenv.2008.10.053.

Azizi, S., Ahmad, M.B., Namvar, F. & Mohamad, R. (2014). Green biosynthesis and characterization of zinc oxide nanoparticles using brown marine macroalga *Sargassummuticum* aqueous extract. *Mater Lett*. (116), 275-277. doi:10.1016/j. matlet.2013.11.038.

Bala, N., Saha, S., Chakraborty, M., Maiti, M., Das, S., Basu R. & Nandy, P. (2015). Green synthesis of zinc oxide nanoparticles using *Hibiscus sabdariffa* leaf extract: effect of temperature on synthesis, anti-bacterial activity and anti-diabetic activity. *RSC Adv*. 5(7), 4993-5003. doi.org/10.1039/C4RA12784F.

Banotra, M., Kumar, A., Sharma, B. C., Nandan, B., Verma, A., Kumar, R., Gupta V. & Bhagat, S. (2017). Prospectus of use of nanotechnology in agriculture – a review. *Int J Curr Microbio App Sci*. 6(12), 1541-1551.

Binupriya, A.R., Sathishkumar, M. & Yun, S. (2010). Biocrystallization of silver and gold ions by inactive cell filtrate of *Rhizopus stolonifera*. *Coll & surf B: Biointer.* 79(2), 531-4. doi:10.1016/j.colsurfb.2010.05.021.

Burman, U., Saini, M. & Kumar, P. (2013). Effect of zinc oxide nanoparticles on growth and antioxidant system of chickpea seedlings. *Tox & Env Chem*. 94(2), 605-612. doi.org/10.1080/02772248.2013.803796.

Chae, S.Y., Park, M.K., Lee, S.K., Kim, T.Y., Kim, S.K. & Lee, W.I. (2003). Preparation of size-controlled tio 2 nanoparticles and derivation of optically transparent photocatalytic films. *Chem of Mat.* 15(17), 3326-3331. doi:10.1021/cm030171d.

Chandrasekaran, R., Gnanasekar, S., Seetharaman, P., Keppanan, R., Arockiaswamy, W. & Sivaperumal, S. (2016). Formulation of *Carica papaya* latex-functionalized silver nanoparticles for its improved antibacterial and anticancer applications. *J Mol Liq.* 219, 232-238. doi:10.1016/j.molliq.2016.03.03839. 122.

Cui, H.X., Sun, C.J., Liu, Q., Jiang, J. & Gu, W. (2010). Applications of nanotechnology in agrochemical formulation, perspectives, challenges and strategies, *International conference on Nanoagri*, Sao Pedro, Brazil, 28-33.

Dahoumane, S.A., Jeffryes, C., Mechouet, M. & Agathos, S.N. (2017). Biosynthesis of inorganic nanoparticles: a fresh look at the control of shape, size and composition. *Bioengi (Basel)*. 4(1), 14. doi:Nd-doped: 10.3390/bioengineering4010014.

Dhandapani, P., Siddarth, A.S., Kamalasekaran, S., Maruthamuthu, S. & Rajagopal, G. (2014). Bio-approach: ureolytic bacteria mediated synthesis of ZnO nanocrystals on cotton fabric and evaluation of their antibacterial properties. *Carbohy Polym.* 103, 448-455. 10.1016/j.carbpol.2013.12.074.

Din M.I. & Rani A. (2016). Recent advances in the synthesis and stabilization of nickel and nickel oxide nanoparticles: a green adeptness. *Int J Anal Chem*. 2016(14), 3512145. doi:10.1155/2016/3512145.

Dreaden, E.C., Alkilany, A.M., Huang, X., Murphy, C.J., & El-Sayed, M.A. (2012). The golden age: gold nanoparticles for biomedicine. *Chem Soc Rev.* 41(7), 2740-2779. doi.org/10.1039/C1CS15237H.

Dwivedi, A.D. & Gopal, K.G. (2010). Biosynthesis of silver and gold nanoparticles using *Chenopodium album* leaf extract. *Coll and Surf a Physicochem & Eng Asp.* 369(1), 27-33. doi:10.1016/j.colsurfa.2010.07.020.

El-Rafie, H.M., El-Rafie, M.H. & Zahran, M.K. (2013). Green synthesis of silver nanoparticles using polysaccharides extracted from marine macroalgae. *CarbohydrPolym*. 96(2), 403-10. doi:10.1016/j.carbpol.2013.03.071.

Elumalai, S., Velmurugan, S., Ravi, V., Kathiravan, S. & Kumar, A. (2015). Green synthesis of zinc oxide nanoparticles using *Moringa oleifera* leaf extract and evaluation of its antimicrobial activity. *Spectrochimica Acta Part A: Mol and Biomol Spectro*. (143), 158-164. doi.org/10.1016/j.saa.2015.02.011.

Eustis, S. & El-Sayed, M.A. (2006). Why gold nanoparticles are more precious than pretty gold: Noble metal surface plasmon resonance and its enhancement of the radiative and nonradiative properties of nanocrystals of different shapes. *Chem Soc Rev*, (35), 209-217.

Ezealisiji, K.M., Siwe-Noundou, X., Maduelosi, B., Nwachukwu, N. & Krause, R.W.M. (2019). Green synthesis of zinc oxide nanoparticles using *Solanum torvum* (L) leaf extract and evaluation of the toxicological profile of the ZnO nanoparticles–hydrogel composite in *Wistar albino*rats, Int Nano Lett. (9), 99–107.

Faivre, D. & Bennet, M.A. (2016). Materials science: Magnetic nanoparticles line up. *Nature.* 535(7611), 235-236. doi:10.1038/535235a.

Fakhari, S., Jamzad, M. & Fard, H.K. (2019). Green synthesis of zinc oxide nanoparticles: a comparison. *Green Chem Lett & Rev*. 12(1), 19-24. doi:10.1080/17518253.2018.1547925.

Fowsiya, J., Madhumitha, G., Al-Dhabi, N.A. & Arasu, M.V. (2016). Photocatalytic degradation of Congo red using *Carissa edulis* extract capped zinc oxide nanoparticles. *J Photochem Photobio Bio.* (162), 395–401. doi.org/10.1016/J.JPHOTOBIOL.2016.07.011.

Guo, D., Xie, G. & Luo, J. (2014). Mechanical properties of nanoparticles: basics and applications. *J Phys & Appl Phys.* (47), 13001. doi:10.1088/0022-3727/47/1/013001.

Gupta, M., Tomar, R.S., Kaushik, S., Mishra, R.K. & Sharma, D. (2018). Effective Antimicrobial Activity of Green ZnO Nanoparticles of *Catharanthus roseus, Front Microbiol*. 9, 2030. doi.org/10.3389/fmicb.2018.02030.

García-Gómez, C., Obrador, A., González, D., Babín, M., Fernández, M. D. (2018), Comparative study of the phytotoxicity of ZnO nanoparticles and Zn accumulation in nine crops grown in a calcareous soil and an acidic soil. *Sci of the Tot Env*. 644, 770-780. doi.org/10.1016/j.scitotenv.2018.06.356.

Hajiashrafi, S. & Motakef-Kazemi, N. (2018). Green synthesis of zinc oxide nanoparticles using parsley extract. *Nanomed Res J*, 3(1), 44-50. doi: 10.22034/NMRJ.2018.01.007.

Hameed, A.S., Karthikeyan, C., Ahamed, A.P., Thajuddin, N., Alharbi, N.S. & Alharbi, S.A. (2016). In vitro antibacterial activity of ZnO and Nd doped ZnO nanoparticles against ESBL producing *Escherichia coli* and *Klebsiella pneumoniae. Sci Rep*. 6, 24312. doi:10.1038/srep24312.

Huang, H.W. (2006). Molecular mechanism of antimicrobial peptides: The origin of cooperativity. *Biochimica et Biophysica Acta (BBA) - Biomem.* 1758(9), 1292-1302. doi.org/10.1016/j.bbamem. 2006.02.001.

Husen, A. & Siddiqi, K.S. (2014). Plants and microbes assisted selenium nanoparticles: characterization and application. *J Nanobiotechnol*. 12, 28. doi.org/10.1186/s12951-014-0028-6.

Ibrahim, K., Saeed, K. & Khan, I (2017). Nanoparticles: Properties, applications and toxicities. *Arab J of Chem*. 12(7), 908-931. doi.org/10.1016/j.arabjc.2017.05.011.

Jean, J.S. & Albertus, K.B. (2011). Evaluation of a low-cost ceramic micro-porous filter for elimination of common disease microorganisms. *Phy & Chem of the Earth*, (36), 14–15. doi:10.1016/j.pce.2011.07.064.

Jain, N., Bhargava, A., Tarafdar, J.C., Singh, S.K. & Panwar, J. (2013). A biomimetic approach towards the synthesis of zinc oxide nanoparticles. *App Microbio & Biotech.* (97), 859–869.

Janotti, A. & Van de Walle, C.G. (2009). Fundamentals of zinc oxide as a semiconductor. *Rep Prog Phys.* 72(12), 126501. doi:10.1088/0034-4885/72/12/126501.

Jayaseelan, C., Rahuman, A.A., Kirthi, A.V., Marimuthu, S., Santhoshkumar, T. & Bagavan, A. (2012). Novel microbial route to synthesize ZnO nanoparticles using *Aeromonas hydrophila* and their activity against pathogenic bacteria and fungi, Spectrochim. *Acta a Mol Biomol Spectro*. 90(78), 84. doi.org/10.1016/j.saa.2012.01.006.

Jha, A.K., Prasad, K. & Kulkarni, A.R. (2009). Synthesis of TiO2 nanoparticles using microorganisms. *Coll & surf B: Biointer.* 71(2), 226-9. doi:10.1016/j.colsurfb.2009.02.007.

Jiang, J., Pi, J. and Cai, J. (2018). The advancing of zinc oxide nanoparticles for biomedical applications. *Bio Chem & App*. 2018, 1062562. doi.org/10.1155/2018/1062562.

Kelsall, R.W., Hamley, I.W. & Geoghegan, M. (2005). Nanoscale science and technology. *John Wiley & Sons Ltd*. doi:10.1002/0470020873.

Khan, F.R., Paul, K.B., Dybowska, A.D., Valsami-Jones, E., Lead, J.R., Stone, V. & Fernandes, T.F. (2015).

Accumulation dynamics and acute toxicity of silver nanoparticles to *Daphnia magna* and *Lumbriculus variegatus*: implications for metal modeling approaches. *Env Sci and Tech.* 49, 4389-4397. doi:10.1021/es506124x.

Khan, I., Abdalla A., & Qurashi, A. (2017). Synthesis of hierarchical WO_3 and Bi_2O_3/WO_3 nanocomposite for solar-driven water splitting applications. *Int J Hydro Ener.* 42(5), 3431-3439. doi.org/10.1016/j.ijhydene.2016.11.105.

Khandagale, P., Shinde, D. (2017). Synthesis & characterization of nickel oxide nanoparticles by using co-precipitation method. *Int J of Adv Res*. 5(5), 1333-1338. doi:10.21474/IJAR01/4253.

Konishi, Y., Ohno, K., Saitoh, N., Nomura, T., Nagamine, S., Hishida, H. & Uruga, T. (2007). Bioreductive deposition of platinum nanoparticles on the bacterium *Shewanella algae*, *J of Biotech.* 128, 648-653.

Korbekandi, H., Iravani, S. & Abbasi, S. (2012). Optimization of biological synthesis of silver nanoparticles using *Lactobacillus casei*. *J of Chem Technol & Biotech.* (87)7, 932-937. doi:10.1002/jctb.3702(7).

Król, A., Pomastowski, P., Rafińska, K., Railean-Plugaru, V. & Buszewski, B. (2017). Zinc oxide nanoparticles: Synthesis, antiseptic activity and toxicity mechanism. *Adv Colloid Interface Sci.* 249, 37-52. doi:10.1016/j.cis.2017.07.033.

Kumar, N.S., Ganapathy, M., Sharmila, S., Shankar, M., Vimalan, M. & Potheher, I.V. (2017). ZnO/Ni(OH)2 core-shell nanoparticles: Synthesis, optical, electrical and photoacoustic property analysis. *J of Alloys and Comp*. 703, 624-632.

Kundu, D., Hazra, C., Chatterjee, A., Chaudhari, A. & Mishra, S. (2014). Extracellular biosynthesis of zinc oxide nanoparticles using *Rhodococcu spyridinivorans* NT2: multifunctional textile finishing, biosafety evaluation and in vitro drug delivery in colon carcinoma. *J Photochem Photobiol B Bio*. 140, 194-204. doi.org/10.1016/j.jphotobiol.2014.08.001.

Kwabena, D.E. & Aquisman, A.E. (2019). Morphology of Green Synthesized ZnO Nanoparticles Using low-temperature hydrothermal technique from aqueous *Carica papaya* extract. *Nanosci and Nanotech.* 9(1), 29-36. doi:10.5923/j.nn.20190901.03,2.

Siddiqi, K.S., Husen, A. & Rao, R.A.K. (2018). A review on the biosynthesis of silver nanoparticles and their biocidal properties. *J of Nanobiotech.* 16, 14. doi:10.1186/s12951-018-0334-5.

Martínez-Carmona, M., Gun'ko, Y., & Vallet-Regí, M. (2018). ZnO nanostructures for drug delivery and theranostic applications. *Nanomater (Basel, Switzerland)*. 8(4), 268. doi.org/10.3390/nano8040268.

Mahajan, P., Dhoke, S.K. & Khanna, A.S. (2011). Effect of nano-ZnO particle suspension on growth of Mung (*Vignaradiata*) and Gram (*Cicerarietinum*) seedlings using Plant Agar Method. *J of Nanotech*. 2011, 696535. doi:10.1155/2011/696535.

Mann, S., Frankel, R.B., & Blakemore, R.P. (1984). Structure, morphology and crystal growth of bacterial magnetite. *Nature*. 310, 405–407. doi.org/10.1038/310405a0.

Mansha, M., Khan, I., Ullah, N. & Qurashi, A. (2017). Synthesis, characterization and visible-light-driven photoelectrochemical hydrogen evolution reaction of carbazole-containing conjugated polymers. *Int J Hydro Ener*. 42(16), 10952-10961. doi.org/10.1016/j.ijhydene.2017.02.053.

Martínková, L., Uhnáková, B., Pátek, B., Nešvera, J. & V. Kren, V. (2009). Biodegradation potential of the genus *Rhodococcus, Env Int.* 35, 162–177. doi:10.1016/ j.envint.2008.07.018.

Mayedwa, N., Khalil, A.T. & Mongwaketsi, N. (2017). The study of structural, physical and electrochemical activity of ZnO nanoparticles synthesized by green natural extracts of *Sageretia Thea*, *Nano Res Appl,* 3(2). doi:10.21767/2471-9838.100026.

Miransari, M. (2011). Soil microbes and plant fertilization, *App Micro and Biotech*. 92(5), 875-85. doi:10.1007/s00253-011-3521-y.

Mittal, A.K., Chisti, Y. & Banerjee, U.C. (2013). Synthesis of metallic nanoparticles using plant extracts. *Biotech Adv.* 31(2), 346-356. doi:10.1016/j.biotechadv.2013.01.003.

Movahedi, F., Masrouri, H. & Kassaee, M.Z. (2014). Immobilized silver on surface-modified ZnO nanoparticles: as an efficient catalyst for the synthesis of propargyl amines in water. *J Mol Catal a Chem*, 395, 52–57. doi:10.1016/j.molcata.2014.08.007.

Nagarajan, S. & Kuppusamy, A.K. (2013). Extracellular synthesis of zinc oxide nanoparticles using seaweeds of the Gulf of Mannar, India, *J Nanobiotech,* 11, 39. doi:10.1186/1477-3155-11-39.

Narayana, A., Bhat, S.A., Fathima, A., Lokesh, S.V., Surya, S.G. & Yelamaggad, C.V. (2020). Green and low-cost synthesis of zinc oxide nanoparticles and their application in transistor-based carbon monoxide sensing, *RSC Adv.* 10, 13532-13542. doi:10.1039/D0RA00478B.

Ochieng, P.E., Iwuoha, E., Michira, I., Masikini, M., Ondiek, J., Githira, P. & Kamau, G.N. (2015). Green route synthesis and characterization of ZnO nanoparticles using *Spathodea campanulata*. *Int J of BioChemiPhy*. 23, 53.

Ombódi, A. & Saigusa, M. (2000). Improvement of Nitrogen Use Efficiency of Tender green Mustard grown in the field during rainy seasons by using polyolefin-coated Urea. *Tohoku J of Agri Res.* 51, 1-2.

Pal, S., Mondal, S., Maity, J. & Mukherjee, R. (2018). Synthesis and characterization of zno nanoparticles using *Moringa oleifera* leaf extract: investigation of photocatalytic and antibacterial activity. *Int J Nanosci Nanotechnol.* 14(2), 111-119.

Patel, P., Agarwal, P., Kanawaria, S. & Kothari, S.L. (2015). Plant-based synthesis of silver nanoparticles and their characterization. *Nanotech and Plant Sci*. 271-288. doi:10.1007/978-3-319-14502-0_13.

Pavani, K.V., Kumar, N.S. & Sangameswaran, B.B. (2012). Synthesis of lead nanoparticles by *Aspergillus* species. *J Microbiol*. 61, 61–63.

Philip, D. (2009). Biosynthesis of Au, Ag and Au–Ag nanoparticles using edible mushroom extract. *Spectrochim Acta*. 73(2), 374-381. doi:10.1016/j.saa.2009.02.037.

Prasad, K. & Jha, A.K. (2009). ZnO nanoparticles: synthesis and adsorption study. *Nat Sci.* 1, 129-135. doi.org/10.4236/ns.2009.12016.

Prasad, T.N.V.K.V., Sudhakar, P., Sreenivasulu, Y., Latha, P., Munaswamy, V., Reddy, K.R., Sreeprasad, T.S., Sajanlal, P.R. & Pradeep, T. (2012). Effect of nanoscale zinc oxide particles on the germination, growth and yield of peanuts. *J of Plant Nutri.* 35(6), 905-927. doi:10.1080/01904167.2012.663443.

Priyadarshana, G., Kottegoda, N., Senaratne, A., Alwis, A.D. & Karunaratne, V. (2015). Synthesis of magnetite nanoparticles by top-down approach from a high purity ore. *J of Nanomats*. 2015, 317312. doi.org/10.1155/2015/317312.

Puri, A., Loomis, K., Smith, B., Lee, J.H., Yavlovich, A., Heldman E., & Blumenthal, R. (2009). Lipid-based nanoparticles as pharmaceutical drug carriers: from concepts to clinic Crit Rev Ther. *Drug Carr Sys*. 26(6), 523-580.

Qi, M., Zhang, K., Li, S., Wu, J., Pham-Huy, C., Diao, X., Xiao, D. & He, H., (2016). Superparamagnetic Fe3O4 nanoparticles: synthesis by a solvothermal process and functionalization for a magnetic targeted curcumin delivery system. *New J Chem*. 40, 4480-4491.

Raj, A., & Lawerence, R. (2018). Green synthesis and characterization of ZnO nanoparticles from leaf's extracts of *Rosa indica* and its antibacterial activity. *Rasayan J Chem.* 11(3), 1339-1348. doi.org/10.31788/RJC.2018.1132009.

Rajan, A., Cherian, E. & Baskar, G. (2016). Biosynthesis of zinc oxide nanoparticles using *Aspergillus fumigatus* JCF and its antibacterial activity. *Int J of Mod Sci and Tech.* 1(I2), 52-57.

Raliya, R. & Tarafdar, J.C. (2013). ZnO nanoparticle biosynthesis and its effect on phosphorus-mobilizing enzyme secretion and gum contents in Cluster bean (*Cyamopsis tetragonoloba* L.). *Agric Res.* 2, 48-57. doi:10.1007/ s40003-012-0049-z.

Raliya, R., Saran, R., Choudhary, K. & Tarafdar, J.C. (2012). Biosynthesis and Characterization of Nanoparticles. *J of Adv in Med and life Sci VIII*.

Rao, M.D. & Gautam, P. (2016). Synthesis and characterization of ZnO nanoflowers using *Chlamydomonas reinhardtii*: A green approach. *Environ Prog Sust Ene*. 35(4), 1020-1026. doi:10.1002/ep.

Rawat, M.K., Jain, A., Singh, S., Mehnert, W., Thunemann, A.F., Souto, E.B., Mehta, A. & Vyas, S.P. (2011). Studies on binary lipid matrix-based solid lipid nanoparticles of repaglinide: in vitro and in vivo evaluation. *J Pharm Sci.* 100(6), 2366-2378.

Reiss, G. & Hütten, A. (2005). Magnetic nanoparticles: applications beyond data storage. *Nat Mat.* 4(10), 725-6. doi:10.1038/nmat1494.

Saeed, K. & Khan, I. (2014). Preparation and properties of single-walled carbon nanotubes/poly (butylene terephthalate) nanocomposites. *Iran Polym J*. 23, 53-58. doi.org/10.1007/s13726-013-0199-2.

Sabir, S., Arshad, M. & Khalil Chaudhari, S.K. (2014). Zinc oxide nanoparticles for revolutionizing agriculture: synthesis and applications. *The Sci World J.* 2014, 925494. doi.org/10.1155/2014/925494.

Saeed, K. & Khan, I. (2016). Preparation and characterization of single-walled carbon nanotube/nylon 6, 6 nanocomposites. *Instru Sci Technol*. 44, 435-444. doi.org/10.1080/10739149.2015.1127256.

Sangani, M.H., Moghaddam, M.N. & Mahdi, M. (2015). Inhibitory effect of zinc oxide nanoparticles on *Pseudomonas aeruginosa* biofilm formation. *Nanomed J*. 2, 121-128.

Saravanakkumar, D., Sivaranjani, S., Umamaheswari, M., Pandiarajan, S. & Ravikumar, B. (2016). Green Synthesis of ZnO nanoparticles using *Trachyspermum ammi* seed extract for antibacterial investigation. *Der Phar Chemi.* 8(7), 173-180.

Sasidharan, P., Raja, R., Karthik, C., Sharma, R.K. & Arulselvi, I. (2013). Isolation and characterization of yellow pigment producing *Exiguo bacterium* sps. *J Biochem Tech.* 4(4), 632-635.

Shah, M.A. & Towkeer, A. (2010). Principles of nanosciences and nanotechnology, Naroosa Publishing House, New Delhi.

Shah, R.K., Boruah, F. & Parween, N. (2015). Synthesis and characterization of ZnO nanoparticles using leaf extract of *Camellia sinensis* and evaluation of their antimicrobial efficacy. *Int J Curr Microbio App Sci*. 4, 444-450.

Shamsuzzaman, A., Mashrai, H., Khanam, R.N. & Aljawfi, R.N. (2013). Biological synthesis of ZnO nanoparticles using *C. albicans* and studying their catalytic performance in the synthesis of steroidal pyrazolines. *Arab J Chem.* 50, S2. doi:10. 1016/j.arabjc.2013.05.004.

Shamsuzzaman, A., Amin, R.S. & Calvin, A.D. (2014). Severity of obstructive sleep apnea is associated with elevated plasma fibrinogen in otherwise healthy patients. *Sleep Breath.* 18, 761-766. doi.org/10.1007/s11325-014-0938-4.

Shang, Y., Hasan, M. K., Ahammed, G. J., Li, M., Yin, H., & Zhou, J. (2019). Applications of Nanotechnology in Plant Growth and Crop Protection: A Review. *Molecules (Basel, Switzerland).* 24(14), 2558. doi.org/10.3390/molecules24142558.

Sharma, V.K., Ria A. & Yngard, R.A. (2009). Silver nanoparticles: green synthesis and their antimicrobial activities. *Adv Coll Interf Sci.* 145(1-2), 83-96. doi:10.1016/j.cis.2008.09.002.

Shende, P., Tanveer, S. & Nagesh, A. (2015). Synthesis and characterization of ZnO nanoparticles using Gigantic Swallow Wort leave using a green chemical reduction method. *Int J of Phy & App*. 7(2), 101-107.

Shivaji, S., Madhu, S. & Singh, S. (2011). Extracellular synthesis of antibacterial silver nanoparticles using psychrophilic bacteria. *Pro biochem.* 46(9), 1800-1807. doi:10.1016/j.procbio.2011.06.008.

Sirelkhatim, A., Mahmud, S., Seeni, A., Kaus, N., Ann, L. C., Bakhori, S., Hasan, H., & Mohamad, D. (2015). Review on Zinc oxide nanoparticles: antibacterial activity and toxicity mechanism. *Nano-micro Lett*. 7(3), 219-242. doi.org/10.1007/s40820-015-0040-x.

Singaravelu, G., Arockiamary, J.S., Kumar, V.G. & Govindaraju K. (2007). A novel extracellular synthesis of monodisperse gold nanoparticles using marine alga, *Sargassum wightii greville*, *Coll Surf B Biointerf.* 57(1), 97-101.

Singh, B.N., Rawat, A.K.S., Khan, W., Naqvi, A.H. & Singh, B.R. (2014). Biosynthesis of stable antioxidant ZnO nanoparticles by *Pseudomonas aeruginosa rhamnolipids*. PLoS ONE. 9(9), e106937. doi.org/10.1371/journal.pone.0106937.

Solanki, P., Bhargava, A., Chhipa, H., Jain, N. & Panwar, J. (2015). Nano-fertilizers and their smart delivery system. Nanotechnologies in food and agriculture. *Springer Inter Pub Switzerland.* 81-101. doi:10.1007/978-3-319-14024-7_4.

Southam, G., Fairbrother, L., Lengke, M.F. & Reith, F. (2009). The Biogeochemistry of Gold, *Elements.* 5(5), 303-307. doi:10.2113/gselements.5.5.303.

Suresh, D., Nethravathi, U., Lingaraju, K., Naika, R., Sharma, S.C. & Nagabhushana, H. (2015). EGCG assisted green synthesis of ZnO nanopowders photodegradation, antimicrobial and antioxidant activities. *Spectr Acta Part A: Mol Biomol Spect.* 136, 1467-1474.

Suresh, J., Pradheesh, G., Alexramani, V., Sundararajan, M. & Hong, S.I. (2018). Green synthesis and characterization of zinc oxide nanoparticles using insulin plant (*Costus pictus D. Don*) and investigation of its antimicrobial as well as anticancer activities. *Adv Nat Sci Nanosci Nanotech*. 9, 015008.

Taiz, L. & Zeiger, E. (2010). Plant Physiology, 5th Edition, Sinauer Associates Inc., Sunderland. 782.

Thomas, S., Harshita, B.S.P., Mishra, P. & Talegaonkar, S. (2015). Ceramic nanoparticles: fabrication methods and applications in drug delivery. *Curr Pharm Des*. 21(42), 6165-6188. doi.org/10.2174/1381612821666151027153246.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R. & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature.* 418, 671-677. doi:10.1038/nature01014.

Trenkel, M.E. (2010). Slow- and controlled-release and stabilized fertilizers: an option for enhancing nutrient use efficiency in agriculture. International Fertilizer Industry Association (IFA) Paris, France. *Ad in Chem Eng & Sci*. 6(4).

Tripathi, R.M, Bhadwal, A.S, Gupta, R.K., Singh, P., Shrivastav, A. & Shrivastav, B.R. (2014). ZnO nanoflowers: novel biogenic synthesis and enhanced photocatalytic activity. *J Photochem Photobio B Biol.* 141, 288-295. doi.org/10.1016/j.jphotobiol.2014.10.001.

U.S. Environmental Protection Agency: Module 3: Characteristics of particles particle size categories. From the EPA Website.

Umar, H., Kavaz, D. & Rizaner, N. (2019). Biosynthesis of zinc oxide nanoparticles using *Albizia lebbeck* stem bark and evaluating its antimicrobial, antioxidant, and cytotoxic activities on human breast cancer cell lines. *Int J of Nano*. 14, 87-100. doi:10.2147/IJN.S186888.

Upadhyaya, H., Shome, S., Sarma, R., Tewari, S., Bhattacharya, M.K. & Panda, S.K. (2018). Green synthesis, characterization and antibacterial activity of ZnO nanoparticles. *American J of Plant Sci.* 9, 1279-1291. doi: 10.4236/ajps.2018.96094.

Mashrai, A., Khanam, H. & Aljawfi, R.N. (2017). Biological synthesis of ZnO nanoparticles using *C. albicans* and studying their catalytic performance in the synthesis of steroidal pyrazolines. *Arabian J of Chem*. 10, S1530-S1536. doi:10.1016/j.arabjc.2013.05.004.

Vert, M., Doi, Y., Hellwich, K.H., Hess, M., Hodge, P., Kubisa, P., Rinaudo, M. & Schué, F.O. (2012). Terminology for biorelated polymers and applications (IUPAC Recommendations 2012). *P & App Chem*. 84(2), 377-410. doi:10.1351/PAC-REC-10-12-04.

Wadhwani, S. A., Shedbalkar, U. U., Singh, R. & Chopade, B. A. (2016). Biogenic selenium nanoparticles: current status and future prospects. *App Microbio Biotechnol.* 100(6), 2555-66. doi:10.1007/s00253-016-7300-7.

Wang, Y. & Xia, Y. (2004). Bottom-up and top-down approaches to the synthesis of monodispersed spherical colloids of low melting-point metals. *Nano Lett.* 4(10), 2047-2050. doi.org/10.1021/nl048689j.

Wang, J.X., Sun, X.W., Yang, Y., Huang, H., Lee, Y.C., Tan, O.K & Vayssieres, L. (2006). Hydrothermally grown oriented ZnO nanorod arrays for gas sensing applications. *Nanotechnol*. 17, 4995.

Wodka, D., Bielaníska, E., Socha, R.P., Elzbieciak-Wodka, M., Gurgul, J. & Nowak, P. (2010). Photocatalytic activity of titanium dioxide modified by silver nanoparticles. *ACS Appl Mater Interf.* 2, 1945-1953. doi:10.1021/am1002684.

Wu, W., He, Q. & Jiang, C. (2008). Magnetic iron oxide nanoparticles: synthesis and surface functionalization strategies. *Nanoscale Res Lett.* 3, 397. doi.org/10.1007/s11671-008-9174-9.

Zhang, D., Ma, X. & Gu, Y. (2020). Green synthesis of metallic nanoparticles and their potential applications to treat cancer. *Front Chem.* 8, 799. doi: 10.3389/fchem.2020.00799.

Zhang, H. ,Ji, Z., Xia, T., Meng, H., Low-Kam, C., Liu, R., Pokhrel, S., Lin, S., Wang, X., Liao, Y., Wang, M., Li, L., Rallo, R., Damoiseaux, R., Telesca, D., Mädler, L., Cohen, Y., Zink, J.I. & Nel, A.E. (2012). Use of metal oxide nanoparticle band gap to develop a predictive paradigm for oxidative stress and acute pulmonary inflammation. *ACS Nano.* 6(5), 4349-4368. doi.org/10.1021/nn3010087.

Zhu, Y., Goodridge, G. & Stapleton, S.R. (1994). Zinc, vanadate and selenate inhibit the tri-iodothyronine-induced expression of fatty acid synthase and malic enzyme in hick-embryo hepatocytes in culture. *Biochem J*. 303, 213-216.

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